MULTI-FUNCTIONAL TRAILER CONCEPT DEVELOPMENT

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by

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PREFACE

This thesis represents the capstone of my five years combined academic work at Kettering University and job experience at RDECOM-TARDEC. Academic experience in Computer Aided Engineering proved to be a valuable asset while I developed this thesis and addressed the problem it concerns.

Although this thesis represents the compilation of my own efforts, I would like to acknowledge and extend my sincere gratitude to the following persons for their valuable time and assistance, without whom the completion of this thesis would not have been possible:

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2. Kenneth Reeves
3. Mark Feury
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I. INTRODUCTION

The U.S Army would like to develop an organic material handling/lift capability within operational transportation units. The main objective of this project is to determine the feasibility of this concept and develop a best technical approach to integrate flexible on-board Material Handling Equipment (MHE) into the Army's future 34 ton semi-trailer concept, the Multi-Functional Trailer (MFT). The resulting best technical approach is shown below in Figure 1.

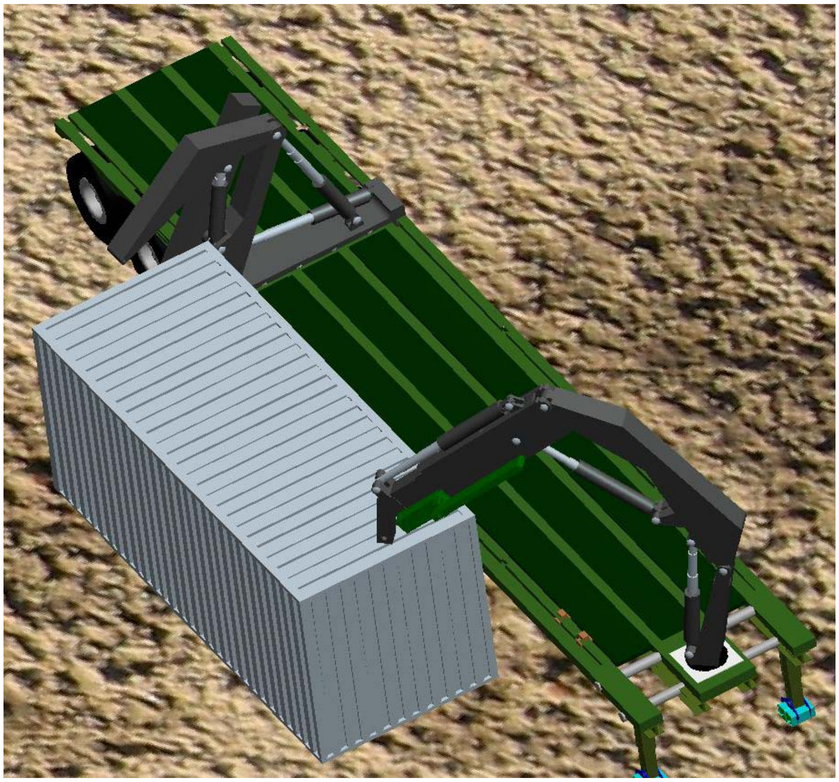

Figure 1: Best Technical Approach, MFT with Side-loading Crane & Smart Crane Loading 20 Foot ISO Container

Problem Topic

Currently the U.S. Army is burdened by the need for specialized material handling equipment vehicles to support its military supply chain. Some of these logistic burdens include: the need to proposition specialized MHE vehicles, significant time delays for loading and off-loading cargo, a larger trailer fleet (than required) and inefficient use of prime movers/tractors (because loaded trailers are often left at their destination point to be unloaded later, at which time the tractors return empty). The U.S. Army Training & Doctrine Command (TRADOC) has identified three tactical wheeled vehicle capability gaps relative to this problem (U.S. DOD, 1/2006):

- Lack sufficient loading, transloading and offloading capability necessary to provide efficient throughput of cargo and equipment in austere areas.
- Lack sufficient on-board MHE to support future forces.
- Current tactical wheeled vehicles cannot load or off-load flatracks from the aircraft.

Background

Current doctrine defines the operational transportation units to be those units that support operations from seaport (SPOD) and/or airport (APOD) to the rear brigade area as outlined in Figure 2 below.

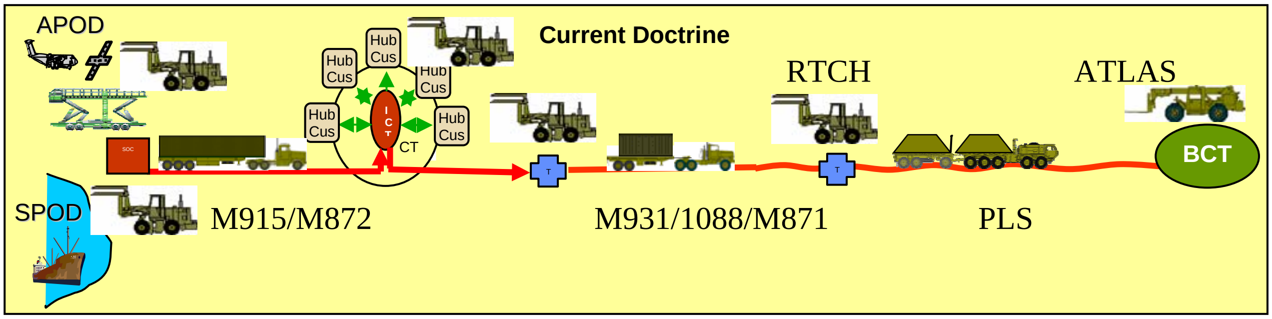

Figure 2: Current Logistics Doctrine (U.S. DOD, 1/2006)

The current operational transportation unit vehicles include the M915 line haul tractor, the M872 34 ton line haul trailer, M1088 & M931/2 five ton tractors, and the M871 22.5 ton general cargo trailer, shown below in Figures 3-7.

Figure 3: M915 Line Haul Tractor

Figure 4: M872 34 Ton Line Haul Trailer with 40 Foot ISO Container

Figure 5: M931 5 Ton Tractor

Figure 6: M1088 5 Ton Tractor

Figure 7: M871 22.5 Ton General Cargo Trailer

The material handling vehicles that support the operational transportation units are owned and operated by the Quartermaster; these vehicles include the Rough Terrain Container Handler (RTCH) and the All Terrain Lifter Army System (ATLAS), and are shown in Figures 8 & 9 below.

Figure 8: Rough Terrain Container Handler (RTCH)

The RTCH is primarily used to handle containers in holding and marshalling areas (FAS Military Analysis Network, 1/2001). It is quite massive, weighing in at 107,030 pounds when equipped with the 20 foot ISO top handler. The RTCH is capable of lifting 50,000 pounds, and has a maximum forward velocity of 18 mph (USMC, nd). A RTCH must be pre-positioned, and is transported in two pieces to forward areas. As such, the RTCH is impractical for use in the middle of a transport route. The MFT would not replace the RTCH, but it would reduce dependency on like vehicles, and would allow them to be used solely in the areas they were designed for.

Figure 9: All Terrain Lifter Army System (ATLAS)

The new operational concept, enhanced by the Multi-Functional Trailer, is outlined in the Emerging Concept Figure 10 below. The MFT has the operational flexibility to bypass distribution centers (shown as a hub and spoke in Figures 2 & 10) and trailer transfer points (shown as blue crosses in Figures 2 and 10) and deliver configured loads directly to the rear brigade area (labeled BCT in Figures 2 & 10). The MFT operational concept is enabled by the integration of material handling equipment into the semi-trailer (please note the elimination of the RTCHs from Figure 10).

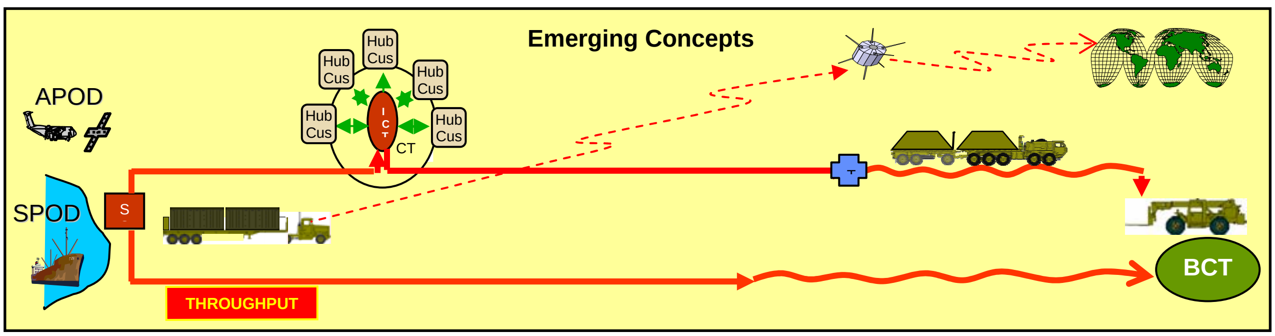

Figure 10 Emerging Logistics Concept (U.S. DOD, 1/2006)

With the multitude of material handling options available for use, the objective then is to pick the MHE system that is best able to perform the required objectives. The eventual material handling equipment choice should provide the best balance between performance and weight, while keeping cost and feasibility into consideration.

Criteria and Parameter Restrictions

The main performance guideline is that the MHE must be trailer mounted and be able to load and unload a wide range of Army cargo and equipment on a 40+ foot trailer bed. The cargo is as follows:

Table 1

<u>Required Cargo</u>

Qty.	Cargo	Dimensions (HxWxL)	Max Weight
1	40 foot ISO	102" x 96" x 480"	67,200 lbs
2	20 foot ISO	96-108" x 96" x 238.5"	52,900 lbs
2	M1 Flatrack	82" x 96" x 238.5"	36,250 lbs
2	M1077 Flatrack	63.5" x 96" x 235.5"	36,250 lbs
2	M3 Flatrack	71.5" x 91.25" x 233"	36,250 lbs
2	Light Combat/Tactical Vehicles	99.3" x 105.8" x 208.5"	26,500 lbs
Mult.	Air Force Pallet 463L	Var. x 88" x 108"	10,350 lbs
Mult.	Generic Wooden Pallets	Var. x 40" x 48"	Variable
1	Helicopter (UH60, AH64, OH58D)	Var. x 96" x 576"	11,000-22,000 lbs

*Note. From MFT JCTD FY07 Proposal (U.S. DOD, 1/2006)

The MHE must also be able to load the cargo in multiple combinations up to its length and/or weight limitations.

The primary limiting factor in choosing proper MHE is meeting the above-listed parameters was MHE is cargo on-load/offload capability. Considered next was Commercial off the Shelf (COTS) availability or similarity. If the desired system has a commercial counterpart, the system will likely have lower design costs and development time than a system that is developed from scratch. Furthermore, many companies have experience providing the military with products, which means that they are familiar with the design requirements associated with the manner and environment that the product will be used in. Money was another parameter to consider, as the lower the cost of the MHE equipment, the greater chance the project has at being funded through completion. Again, a design with a COTS counterpart would have an advantage due to mass production of similar products.

Given an approximate weight budget of 23,500 pounds for the MHE-equipped trailer, weight can quickly become an obstacle for some MHE options. However, the importance of the MHE weight can be mitigated by additional abilities of the system such as being able to load another trailer with the required cargo. Complexity was another restriction to keep in mind, but was directly related to weight and cost. A complex MHE system would be heavier, costlier, and require more development time and money. Weight, complexity, and cost were all used as deciding factors when choosing the final MHE design.

Methodology

The methodology used in determining the best MHE solution for the project began with consulting the material handling experts to see what options were even feasible. From there, research was done on available COTS products to see what current technology was capable of. Next, initial choices were made and eliminations were made based on capability. Finally, CAD scenarios were created to visually represent operation capability and make a final decision.

Primary Purpose

This thesis presents the results from the investigation into the best solution for trailer-mounted MHE.

II. CONCLUSIONS AND RECOMMENDATIONS

Given the wide array of cargo that the MFT is required to lift, from large ISO containers to small generic wooden pallets; the number of possible solutions was limited. In addition, the high weight of the ISO containers and the overall required combined weight of the trailer and MHE made the weight of the MHE a big consideration. After narrowing the available choices down to two, the final decision was made on based on the overall ability of the system.

Table 2

<u>MHE System Capability</u>

MHE	Transloading	40' ISO	(2) 20' ISO	Flatrack	Vehicle	463L/Pallets	Helicopter
Dual Side Loaders	YES	YES	YES	YES	YES	NO	YES
S. Crane/Side Crane	YES	YES	YES	YES	YES	YES	YES
Hydraulic Trailer	NO	YES	YES	YES	YES	NO	YES
Tiered System	YES	YES	YES	YES	YES	YES	YES

The best choice for material handling equipment for the MFT is the smart crane and side loader system. The system is able to load and unload all of the required cargo in the most practical manner. The front truck mounted crane provides a huge leap in functionality by allowing easy loading of palletized items and vehicles from either side of the trailer. The crane can mimic the motions of a crane for quick, easy lifting of ISO

containers and flatracks. The system would reduce the logistic footprint of the army supply chain by allowing retrieval of existing ISO containers that would normally be left behind after they are dropped off. The MHE would also provide enhanced ability of any group of trailers that it is grouped though its ability to load other trailers.

III. SUPPORTING CHAPTERS

The main objective of this project is to determine the best technical approach to integrate flexible on-board Material Handling equipment into the Army's future semi-trailer concept. The Army already has current and future vehicles that can load and unload 20 foot ISO containers; however it is reliant on separate MHE vehicles to load 40 foot ISO containers. The Material handling equipment must be able to load and unload a multitude of Army cargo.

In looking at the available MHE options available COTS or currently in use by the army, my first step was to look at the functionality of the system. After I established an option that would meet nearly all of the desired criteria, I next looked at the feasibility of that option from a cost and weight viewpoint. Below are the primary options that were explored as well as secondary options that were eliminated at an early stage of consideration.

Option 1: Dual Side Loader System

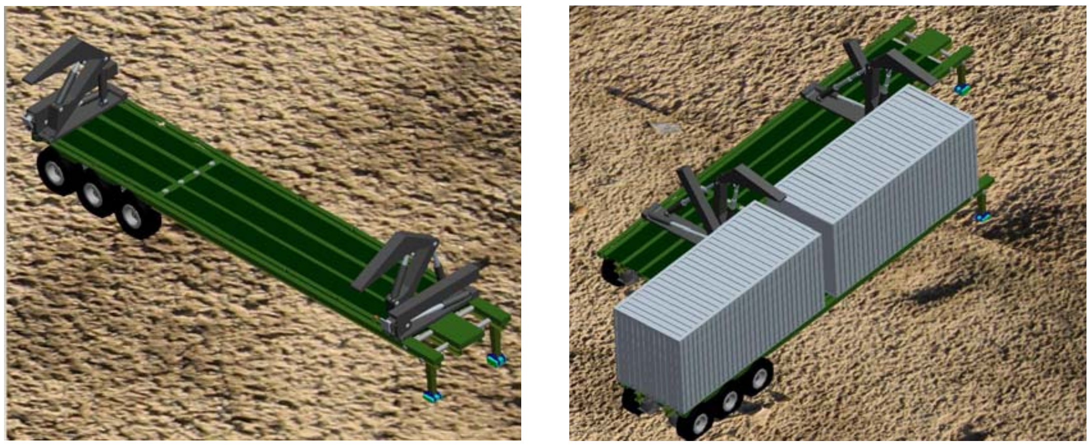

Figure 10: Simulated Dual Side Loader Crane-Equipped Trailer

Side loading trailer systems are very popular in Europe, New Zealand, and Australia. Most of the leading manufacturers are, or have been, based in each of those places. Side loading trailers are used less frequently and are less known about in America. Their ease of use and compactness are benefits that make the systems worth a look at by the U.S. Army. In fact, the New Zealand Army has used side loading trailer systems for several years (Swing Thru International, nd). Because cranes are readily available from several companies, commercial systems are available for purchase and demonstration. Systems are available in the 30-36 tonne range, which is enough to lift the heaviest object required of the MFT.

Side loading trailers are quite adept at lifting ISO boxes (20 foot and 40 foot) as well as flatracks. Typical systems from Hammar Maskin, Swing Thru, and SteelBro have side loading cranes are capable of translating back and forth along the trailer to pick up 20 to 40 foot cargo. Swing Thru also offers crane kits that can mount and demount from trailers. Its cranes are also bidirectional, meaning they can load and unload from either side of the trailer. Hammar and SteelBro commercial systems offer one sided loading and unloading, however they are usually lighter than comparable Swing Thru systems.

Figure 11: Dual Side Loader Crane Trailer with 40 foot ISO

Figure 12: Side Loader Lifting ISO

Figure 13: Front Side Loader Crane in Position to Lift 20 foot ISO

Figure 14: Rear Crane in Position to Lift 20 foot ISO

As stated above, the cranes would have no problem loading and unloading ISO containers and flatracks. Additionally, nearly anything that the hooks of the side loading cranes can lock into will be able to be loaded and unloaded, including rolling stock like light combat and tactical vehicles. Light combat and tactical vehicles have lifting points for chains to hook into. When a 20 foot ISO is carried solo it is loaded in the middle of the trailer. Lifting two 20 foot ISO containers would require a little maneuvering. This can be worked around in one of two ways. The first method would be to lock the two 20 foot ISO boxes together, and lifting them as one 40 foot unit. ISO containers are standardized, and have the locks necessary to perform the task, but this task may be

difficult when the ISO containers are in different locations. The second way would be to transfer the ISO boxes from the MHE-equipped trailer to a standard flatbed trailer. This would allow the MHE equipped trailer to load multiple 20 foot ISO boxes without having to use the ISO locks to lift it as a single 40 foot ISO container. For diagrams of dual side loading crane system cargo scenarios, please see Appendix A-1.

The same transloading methodology could be used in loading the various flatrack types. A singular MHE trailer would have difficulty lifting two flatracks due to the limited fore-aft translation of the cranes, but would have no problem loading two Flatracks onto another trailer without MHE. This would address the loading and unloading of the M1, M3, and M1077 flatracks.

The UH60 helicopter is narrow enough to fit on a trailer; however at 576 inches of length, it is too long to fit on a standard trailer. It would have to be lifted by the MHE-equipped trailer and loaded onto a standard trailer with a portion overhanging the back end, or put on a lengthened trailer.

Figure 15: Bushman Model 900 Pallet Lifter (Bushman Equipment, Inc., 2000)

Lifting palletized items with a dual system would be difficult and inefficient. Vertical pallet lifters are commercially available from such companies as the Bushman; however with only one degree of freedom in the cranes, self loading the pallets would not be possible. Loading another trailer with the pallets would be time consuming and unpractical. Furthermore, pallet lifters such as the Bushman Model 900 Fixed Fork Pallet Lifter capable of lifting the weight fully loaded 463L pallet at 10,000 pounds would weigh between 1300 and 1700 pounds (Bushman Equipment, Inc., 2000). The weight and size would prohibit stowage, retrieval and usage.

Option 2: Side Loader and Smart Crane

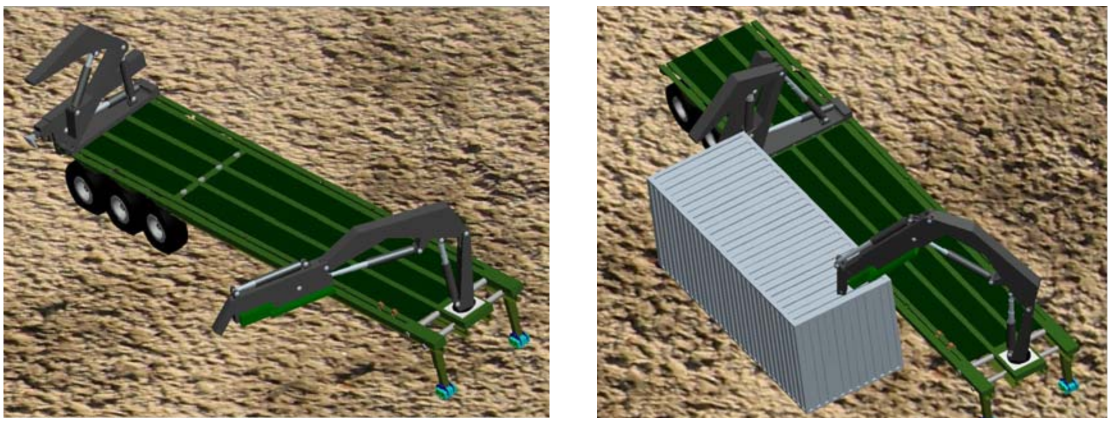

Figure 16: Simulated Smart Crane and Side Loader Crane-Equipped Trailer

From the beginning, a smart crane was an attractive option due to its flexibility. In this context, a smart crane is similar to a traditional truck mounted crane with the exception that is able to accept different end connectors such as forks to load pallets. Given the crane's range of rotation and its ability to articulate in multiple ways, it is perfectly suited to loading and unloading generic wooden pallets and Air Force 463L pallets. Its further range would also make loading vehicles much easier than in a dual side loader crane system. Loading from the side of the trailer, there is no reasonable way that a singular crane could pick up a fully loaded 40 foot ISO by itself. A supplementary lifting mechanism would be necessary.

As described previously, cranes are good option for loading standardized cargo such as ISO containers and flatracks. A second smart crane would provide redundant

functionality and would only add extra weight, so a singular translating side loader with one dimension of freedom would be a good compliment to the smart crane. A helicopter could be lifted by the chains of the two cranes.

Truck mounted cranes are available from companies such as Hiab and Manitowoc Crane Group, in a variety of sizes. The next issue is how big of a crane is required to meet the performance requirements. Truck mounted cranes are typically rated in lifting capacity at a certain distance. Some math is necessary to calculate the moment to find the appropriate commercial crane model.

Table 3

ISO Container Loading on Crane

ISO Length Requirements:		**Unit**
From center of trailer bed	49.5	inch
To edge of ISO	39.36	inch
To center of ISO	48	inch
Total	**136.86**	inch
Crane Loading		
40 foot ISO	67,200	lb
Weight distribution	0.50	
Loading	33600	lb
Moment	4598496	in*lb
	383208	ft*lb
	52.98	tonne meters

The table above shows the weight the crane would need to lift and at what distance it would be required to lift the fully loaded 40 foot ISO. The crane would not be

required to lift 100% of the ISO weight because the task would be split between the smart crane and the crane. A fully loaded 40 foot ISO would be the heaviest object the crane would be required to lift in conjunction with the crane. From the weight and distance the moment is calculated, which is used to pick the proper crane for weight projections.

The crane would also be required to lift some objects without the aid of the side loading crane. It is then necessary to check the heaviest object the crane would be required to lift at the proper distance to check if that moment is greater than that of the tandem lifting. The heaviest object that smart crane would lift on its own would be an Air Force 463L pallet. All flatracks would be lifted in tandem with the side loading crane.

Table 4:

Air Force 463L Pallet Loading on Crane

Air Force Pallet 463L		**Unit**
From center of bed	49.5	inch
To edge of pallet	120	inch
To center of pallet	54	inch
Total	223.5	inch
Crane Loading		
463L Pallet	10,350	lb
Moment	192768.75	ft*lb
	26.65	tonne*meter

The chart above shows the calculations to find the moment that the smart crane would experience from lifting a 463L pallet. The moment is found to be less than the

smart crane would be exposed to lifting a 40 foot ISO. Thus, the moment found lifting a 40 foot ISO would be the criteria used to choose the proper crane.

Figure 17: Hiab 500 Truck Mounted Crane

Hiab conveniently provides extensive information of its full line of cranes, which allows for a good estimate of the weight necessary to meet the performance criteria. The driving criteria in choosing the right crane would be 52.98 tonne meters required to lift a 40 foot ISO. The first models in that range of capability include the Hiab XS 600 and the Hiab 500. The XS 600 model is rated at 51 to 57 tonne meters, while the 500 model is rated at 50 tonne meters. The XS 600 model, in its lightest form, weighs approximately 12,236 pounds. This is over half of the approximate 23,500 pound weight budget of the

entire system. The problem is further exacerbated by the added weight of the stabilization equipment, which scales in between 2,469 and 2,745 pounds. Stepping down further into the Hiab model range does not yield much better results. The aforementioned Hiab 500 model is rated just below the necessary lifting capacity required, yet is not substantially lighter. The weight of the 500 crane in its lightest variant is 9,767 pounds, not including the 2,491 to 2,734 pound stabilizer equipment.

Seemingly the weight of the crane would be enough to eliminate it as a primary solution for the MHE of the Multi-Functional Trailer; however the ability to load another trailer with fully loaded ISO would marginalize any issue caused by the weight of the crane. Heavier objects could be loaded onto other trailers, while loading lighter objects onto the bed of its own trailer.

Secondary Option 1: Tiered Sytem

A different approach would be to use a tiered MHE system, using the crane system on one trailer and a crane on another. The cranes could be used to lift the heavy ISO boxes and flatracks, and the crane could be used to lift the lighter cargo.

The crane would be used to lift wooden pallets, 463L Air Force pallets, and vehicles. The question then again becomes how big of a crane would be required to lift those items. Based on the calculations in Table 4, the crane must be capable of around 27 tonne meters. Based on the line of cranes from Hiab's website, the most appropriate model would be the Hiab 280-2. The crane has a weight of 5,732 pounds, and combined

with the stabilization kit comes in between 6,670 and 7,100 pounds. This would be light enough to likely meet the overall weight limit for the trailer.

Figure 18: Hiab 280 Truck Mounted Crane

Although the tiered system has desirable qualities, it cannot be considered a primary option for the Multi-functional MFT. The task was to determine the best MHE option on a singular trailer. Using two trailers to accomplish to goal of one would complicate the logistics footprint of the supply chain. It would require an extra driver, separate maintenance, another contract, and extra fuel.

Secondary Option 2: Hydraulic Trailer

Hydraulic trailers are another type of commercially available system that is worth a look at for the MFT. They are available in high load capacities and are generally within the desired weight limit. They are adept at loading vehicles as well as ISO containers.

Figure 19: Landoll 317C (Landoll Corporation, 2006)

A high-profile manufacturer of hydraulic-lift trailers is Landoll. They have a wide product range of trailers, including heavy-duty versions that have capacities of 70,000 or 100,000 pounds of cargo. Furthermore, they also provide an Army National Guard version of their 600 Series heavy duty hydraulic trailer.

The 600 Series SLOT (Self-Loading/Off-Loading Trailer) is of particular relevance. It is capable of loading/offloading two 20 foot ISO containers, one 40 foot

ISO container, and wrecked vehicles through an integrated hydraulic winch. It is also capable of loading a mix of cargo (Landoll, 600 Series SLOT).

There are several drawbacks associated with a 600 Series SLOT-type trailer. It is made more for vehicles and large containers, so smaller cargo would be a difficult to load and unload. The hydraulic trailers do not have the same functionality of some of the competition. Specifically, it was not designed for loading and unloading other trailers, which is a major advantage of the cranes. This would reduce retrograde capability to the trailers with the hydraulic capability.

Because hydraulic trailers are not capable of loading other trailers and to see their full benefit, the entire fleet of semi trailers would have to be replaced for full functionality. This is not a viable option because it would marginalize the current line of army trailers instead of augmenting them as the trailers do.

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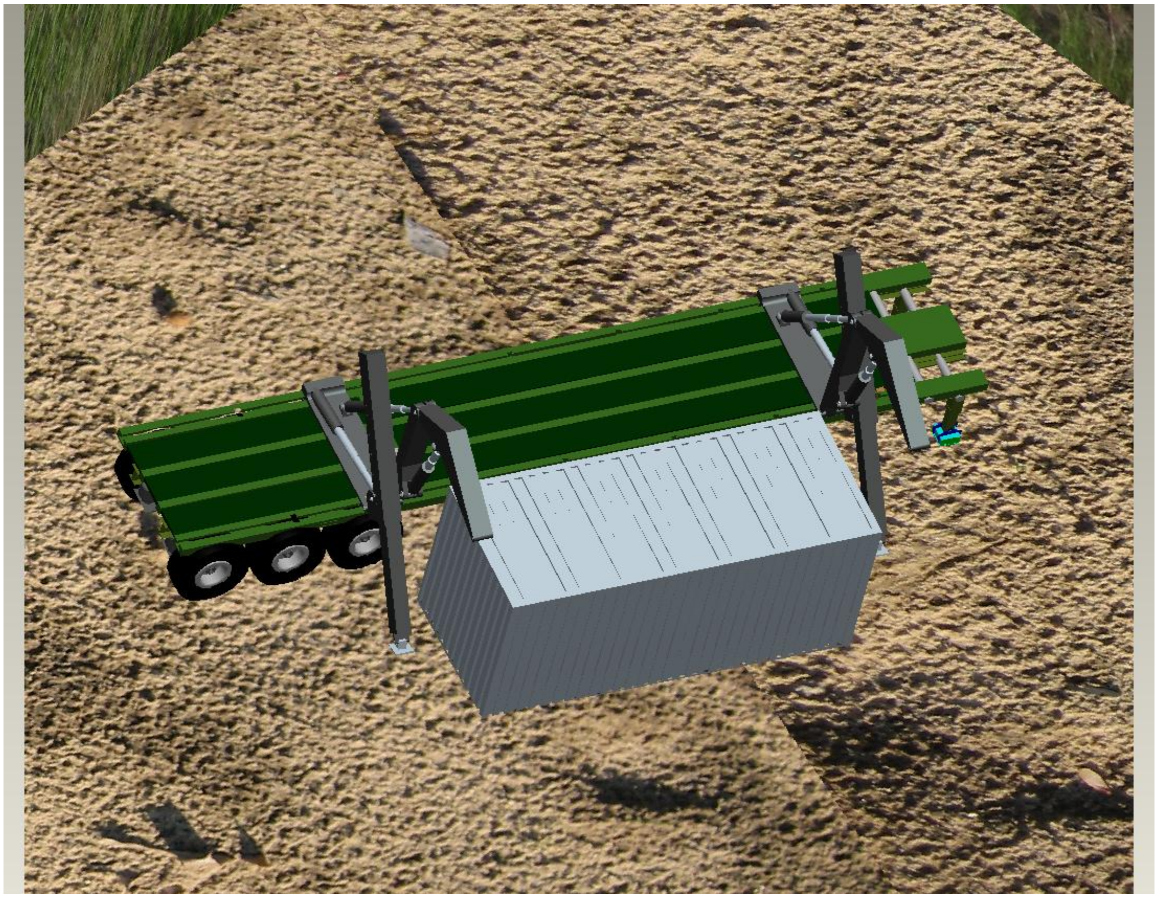
APPENDICEX A-1

Cargo Lifting Scenarios for Dual Crane System

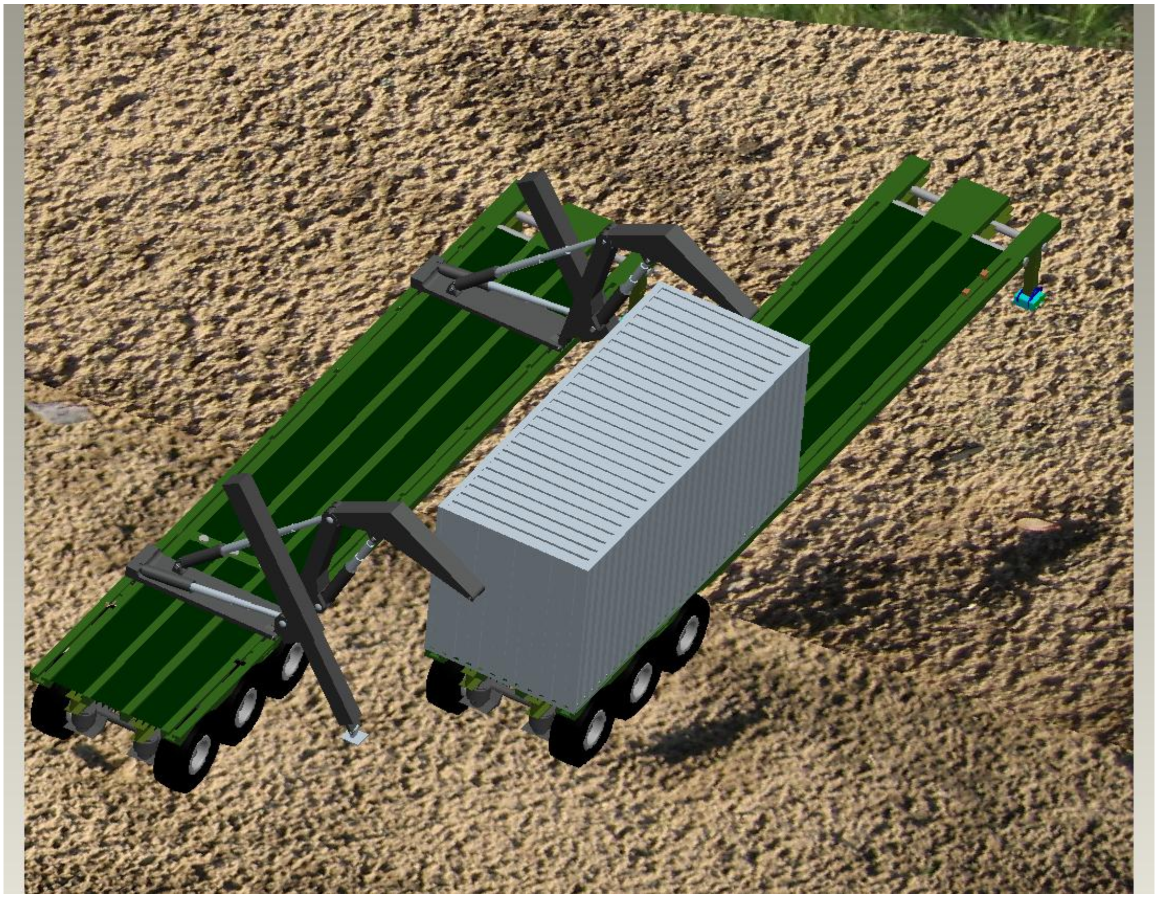
MFT Cranes in Position to Lift a Water Tank Flatrack

MFT Cranes in Stowed Position with Flatrack Loaded

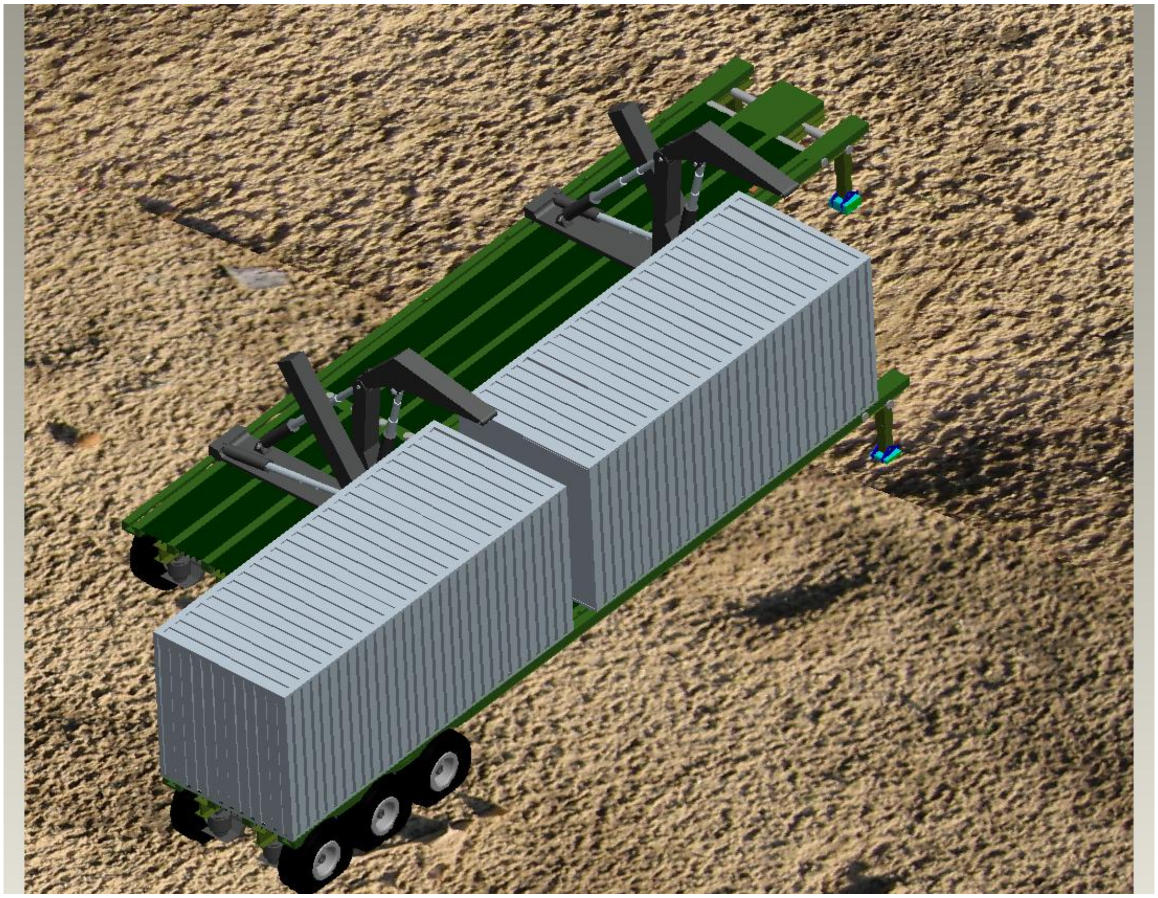


MFT Cranes in Position to Lift 20 foot ISO Container

MFT Cranes after Loading 20 foot ISO Container



MFT Trans-loading 20 foot ISO Container onto a Basic Flatbed Trailer



MFT Trans-loading a Second 20 foot ISO Container onto a Basic Flatbed Trailer

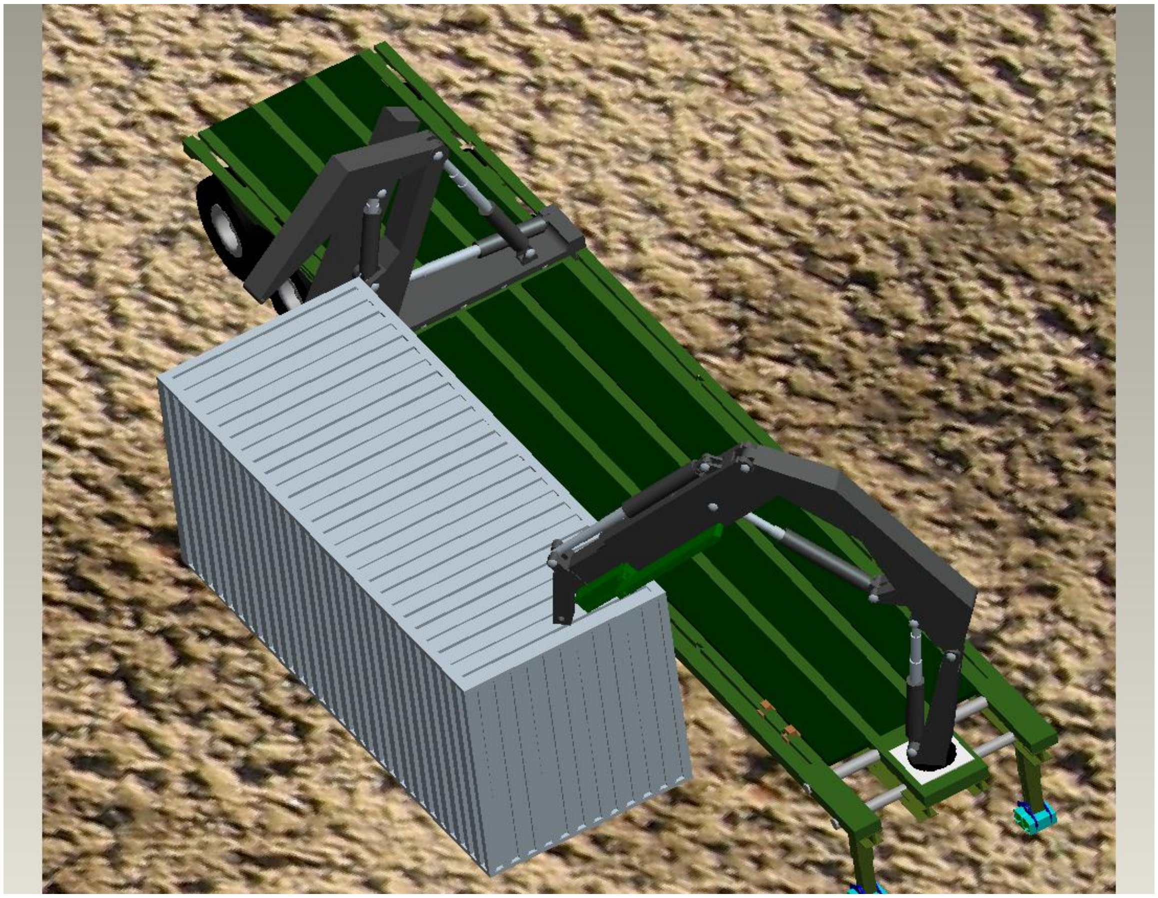
MFT Cranes in Position to Load a Vehicle

APPENDICEX A-2

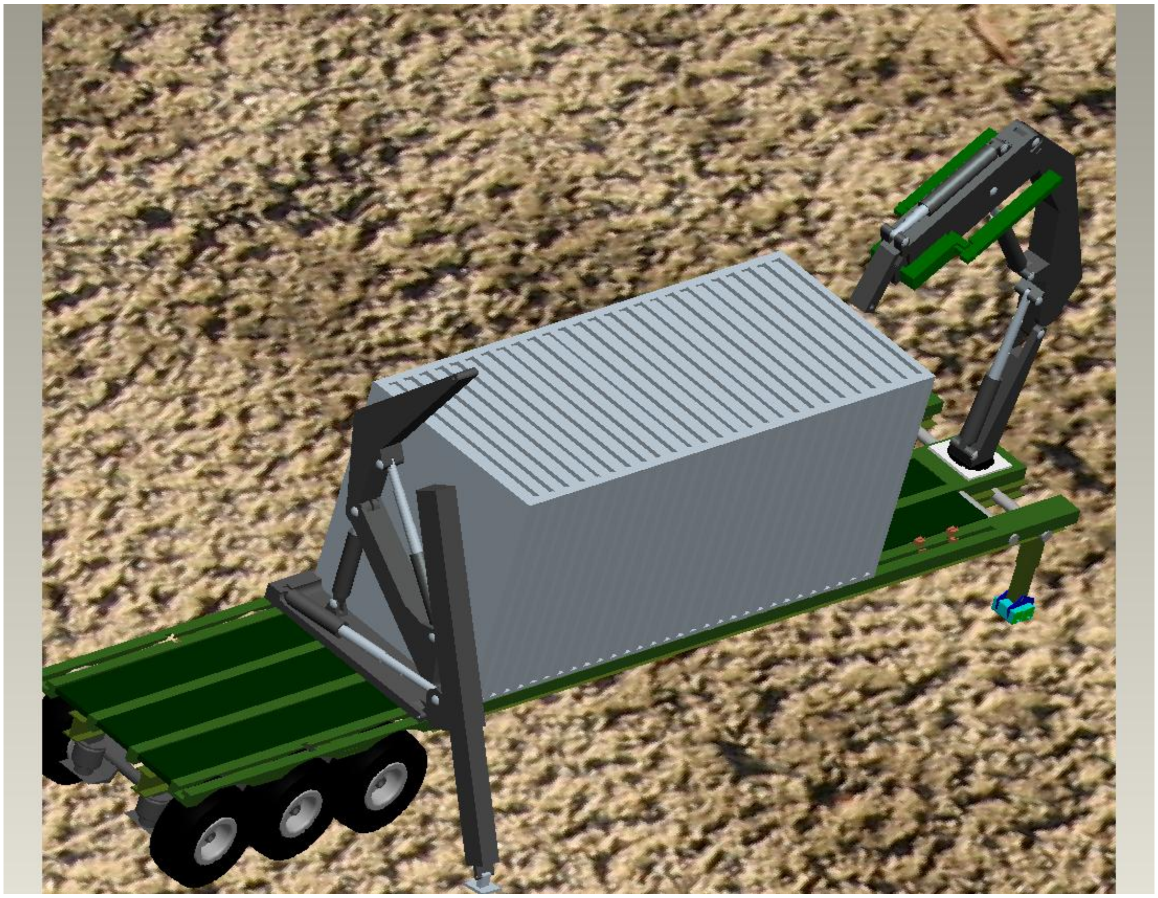
Cargo Lifting Scenarios for Smart Crane and Side-loading Crane System

MFT Cranes in Position to Lift Water Tank Flatrack

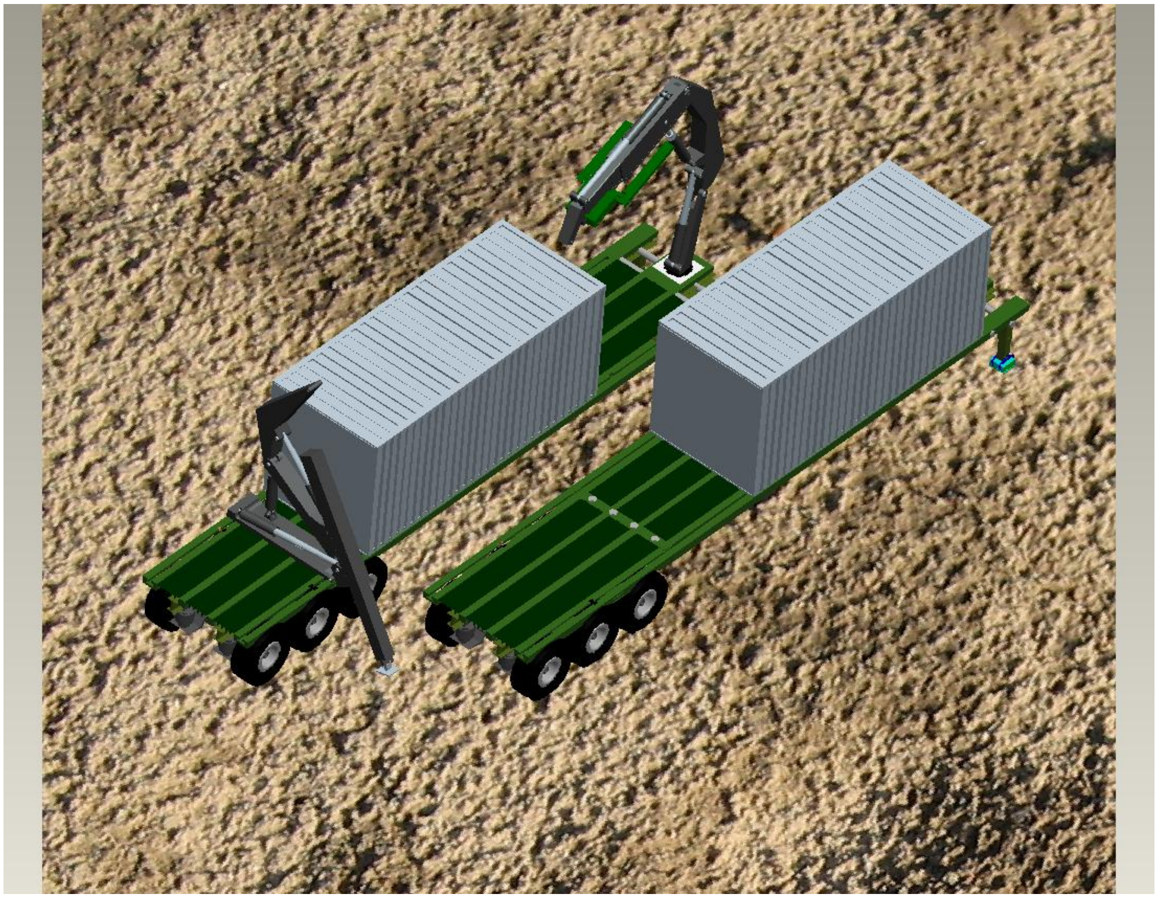
MFT Cranes in Standard Position with Flatrack Loaded



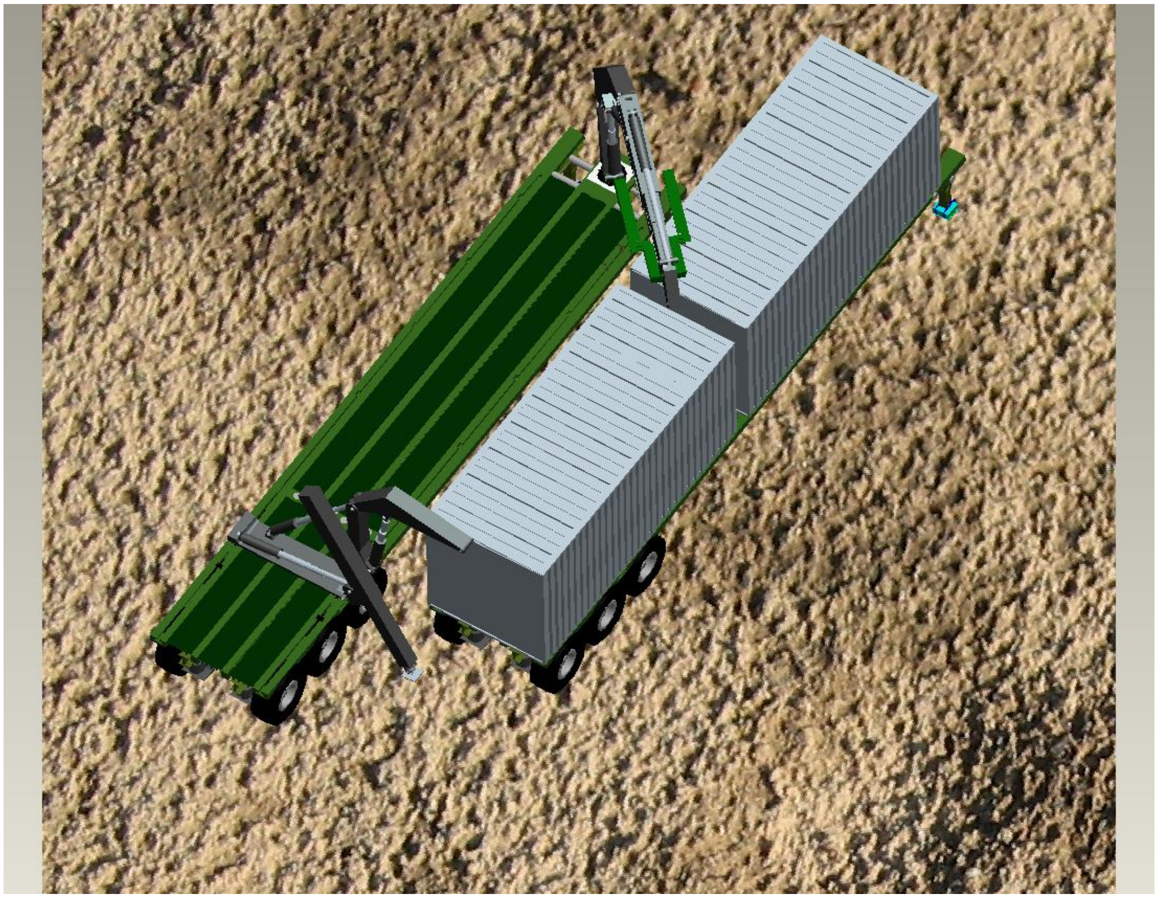
MFT Cranes in Position to Lift 20 foot ISO Container



MFT Cranes in Position to Trans-load ISO Container

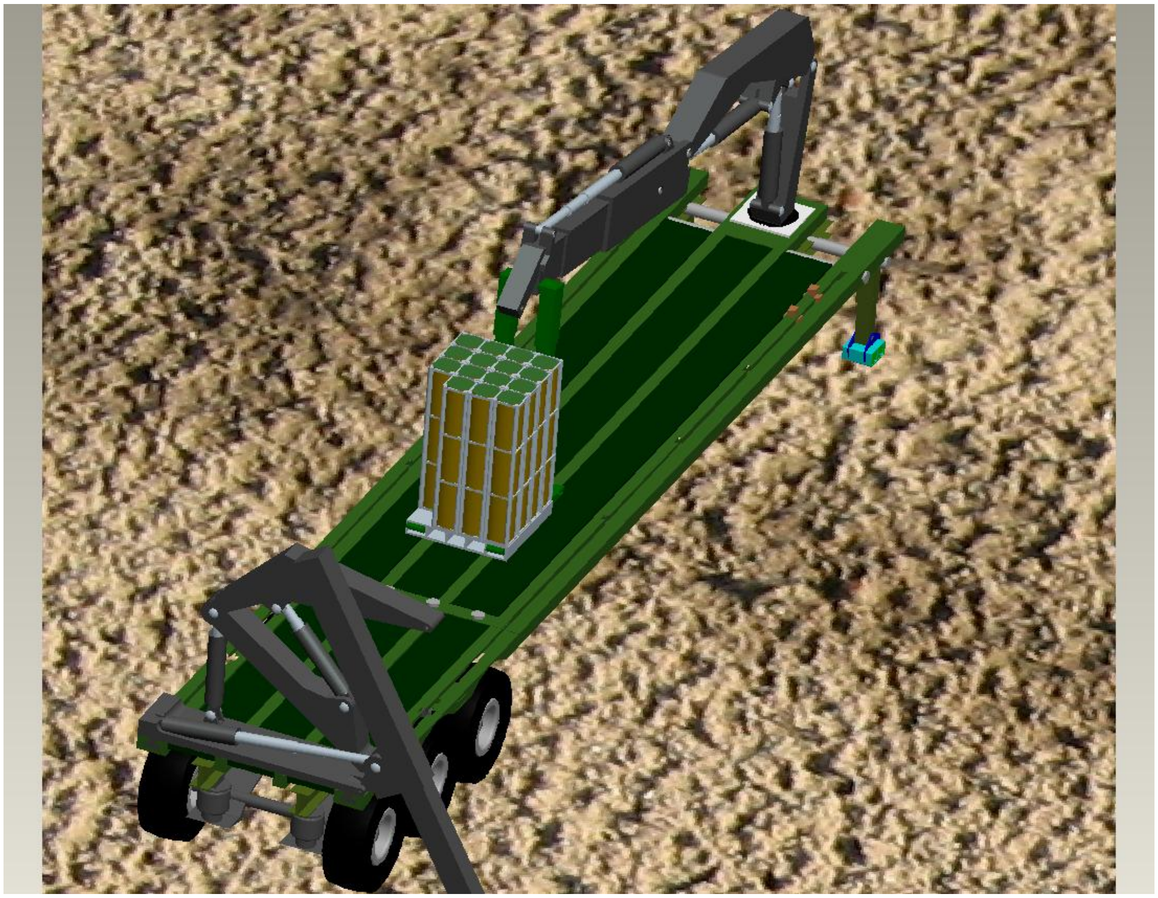


MFT Cranes Loading Second ISO Container onto a Basic Flatbed Trailer



MFT Trans-loading Operations Complete

MFT Smart Crane Fork Lifting Palletized Item



MFT with Palletized Item Loaded